EDI CON 2019
Electronic Design Innovation Conference
电子设计创新大会

April 1-3, 2019
China National Convention Center
Beijing, China

Exhibition Hours
April 1: 11:00-17:00
April 2: 9:30-17:00
April 3: 9:30-13:00

Beamforming measurements

Markus Loerner, Market Segment Manager – RF & microwave component test

ROHDE&SCHWARZ

Phased Arrays – not a new concept

- Phased Array Radars: since the 60’s
- Beams are steerable electronically not by physical movement of the antenna
- Beams can be steered very quickly and multiple beams can be formed to track multiple targets
- Airborne Radar systems:
  - X and Ku Band (8-18 GHz)
  - ~1,000 radiators
- Ground based Radar systems:
  - L and S bands (1-4 GHz)
  - 100’s of radiators
- Ship based Radar systems
  - S and X band (3-12 GHz)
  - Up to 5,000 radiators/antenna

Airborne

Ground

Shipboard

Phased array applications

Platform trends

- 5G going pushes to beamforming
- Satellite payloads and ground stations for LEO systems
- EW systems starting for jamming and ESM
- Radars used phased arrays since the 60’s

Enabling technologies

- MMIC insertion is driving the price of systems down (multiple TRX channels on a chip)
- SiGe/LDMOS/CMOS allows high integrations of RF frontend with beamformer and amps
- GaN is mature and the PA process for PA’s. High power densities, smaller PA’s
- Higher frequencies are allowing the use of smaller apertures and PCB printed antennas
- Higher performing, lower loss PCB laminates are allowing printed antennas

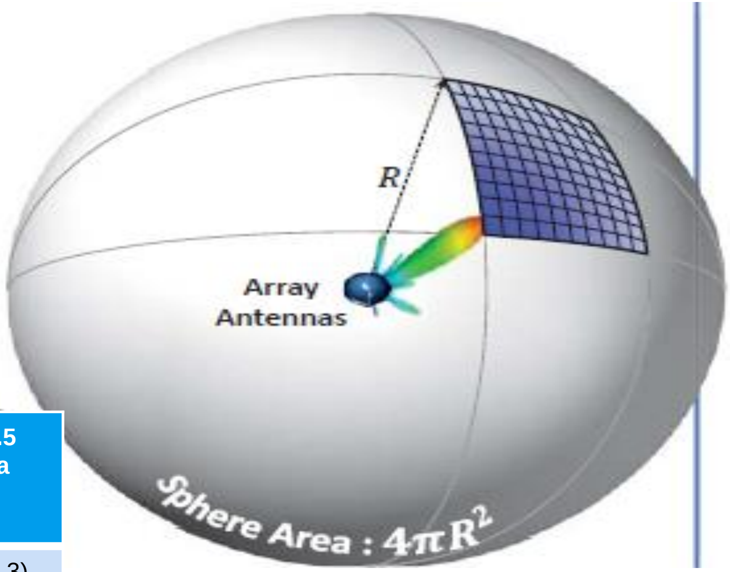
Higher frequencies: path loss issues

Higher frequencies = higher attenuation
Higher frequencies = smaller antennas

Friis equation

$$\frac{P_{Rx}}{P_{Tx}} = G_{antenna}\left(\frac{c}{4\pi f d}\right)^{\gamma}$$

Beamforming

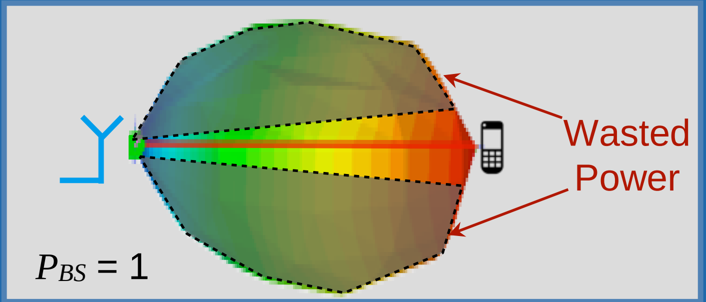


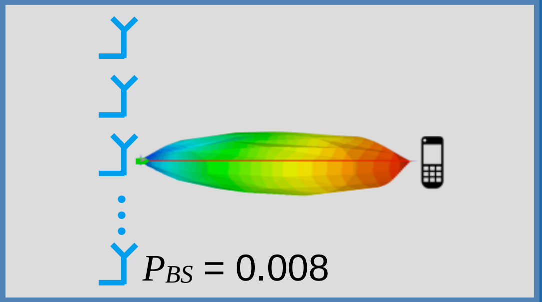
EXAMPLE @ 28 GHz:

PathLoss 28 GHz	γ = 2 Free Space	γ = 1.6 to 1.8 Indoor LOS	γ = 2.7 to 3.5 Urban Area
1 m	- 61,4 dB	- 52 dB (k=1,7)	-92,1 dB (k = 3)
10 m	- 81,4 dB	-69 dB	-122,1 dB
100 m	- 101,4 dB	-86 dB	- 151,1 dB
1000 m	- 121,4 dB	-103 dB	- 181,1 dB

γ = path loss exponent

Energy Efficiency: Why Massive?





Number of Antennas = 1		Number of UEs: 1 120 antennas per UE
Number of BS Transmit Antennas	1	120
Normalized Output Power of Antennas	$P_{ant} = \frac{1}{M_t} = 1$	$P_{ant} = \frac{1}{M_t^2}$
Normalized Output Power of Base Station	$P_{total} = \sum_{i=1}^{M_t} P_{ant}^i = 1$	$P_{total} = \sum_{i=1}^{M_t} P_{ant}^i = 0.008$

Source: IEEE Signal Processing Magazine, Jan 2013

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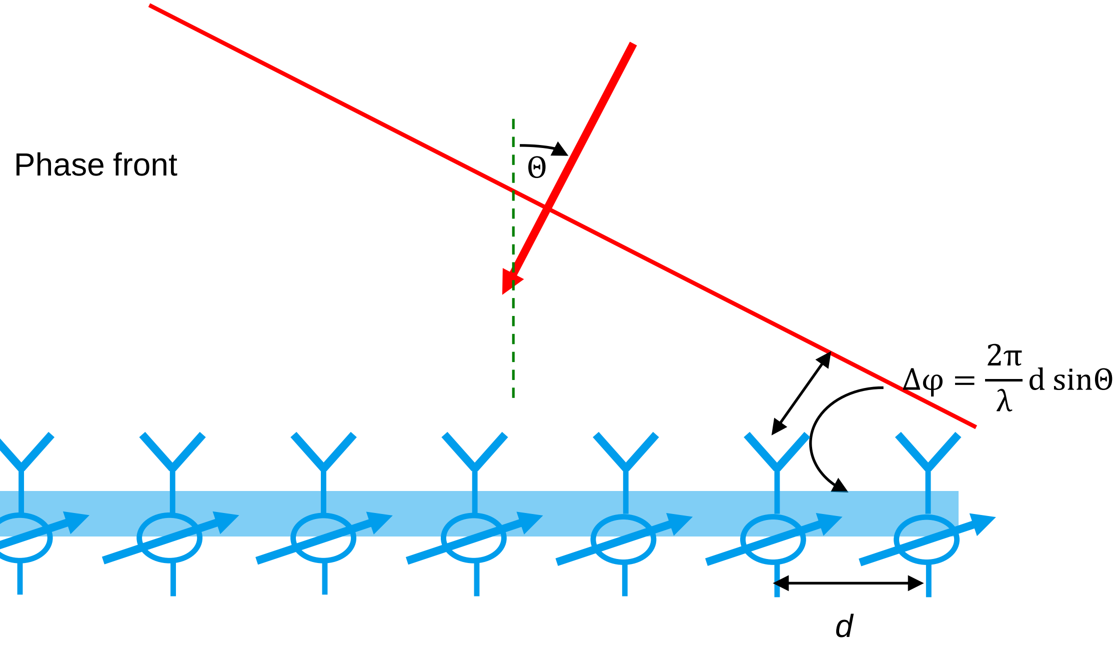
Easiest way to improve energy efficiency: more antennas

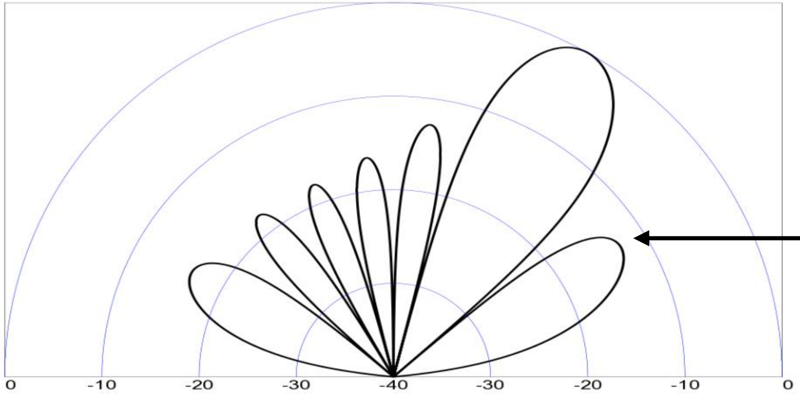
Excurse: Phased Array Antenna Principle

Example: Linear array
- Direction of incident signal with angle Θ
- Phase front reaches antenna elements at different times

Basic concept
- Compensate for phase difference
- Add phase shifters behind each antenna element!



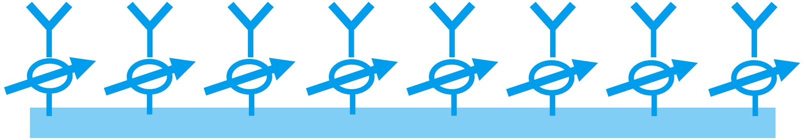
Excurse: Phased Array Antenna Principle



Advantage:
Main beam direction steerable with phase shifters

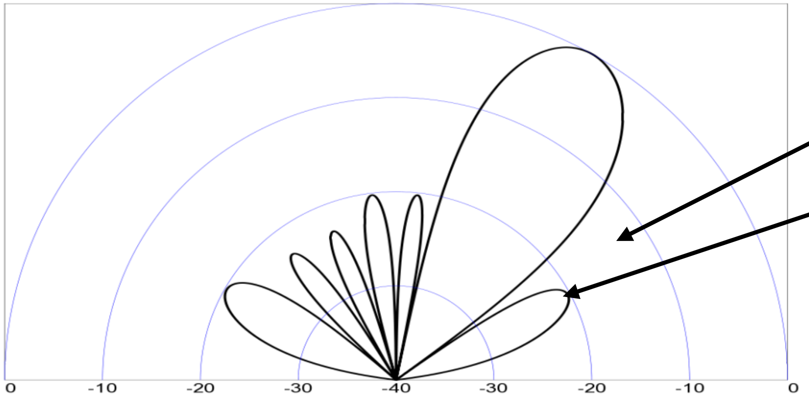
Problem:
Still high side lobe level

How to get side lobe level down?



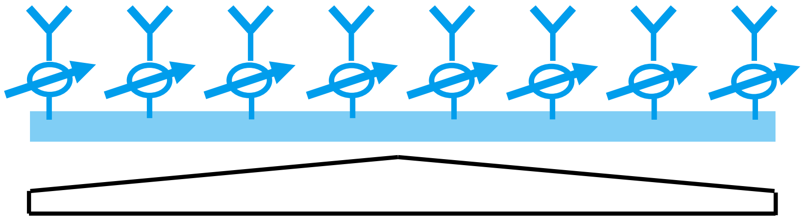
phase shifters:
Weighting by phase

Excurse: Phased Array Antenna Principle



Question:
How to get side lobe level down?

Answer:
Additional weighting by magnitude!

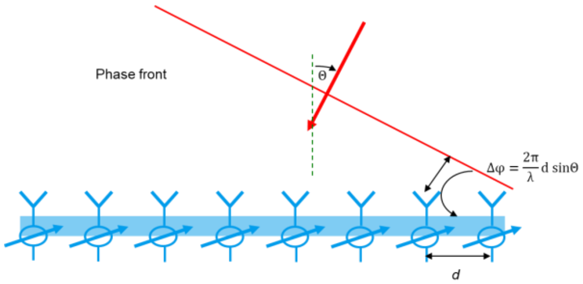


weighting phase and magnitude

Triangular weighting function

How do phase arrays work?

What happens as the Tx/Rx frequencies increase?

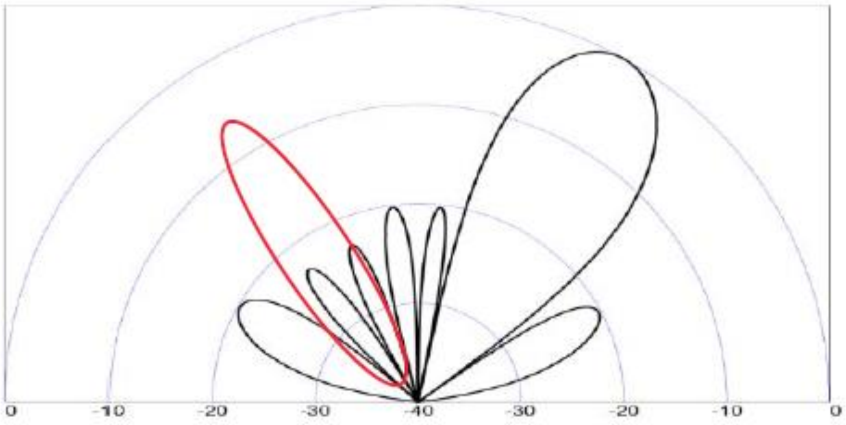


Θ: angle between the lobe and the antenna
➔ no change
λ decreases as the frequency increases

$$\Delta\varphi = \frac{2\pi}{\lambda} d \sin\Theta$$

➔If we want to keep Δφ constant, then ‘d’ (the distance between the antennas) has to decrease

If we do nothing, then multiple side lobes will appear



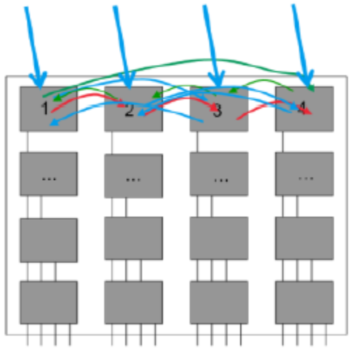
How do phase arrays work?

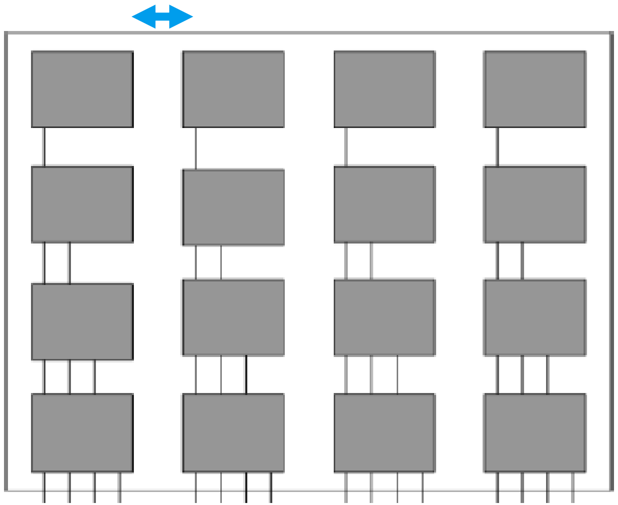
What happens as the Tx/Rx frequencies increase?

Element spacing needs to be < λ/2

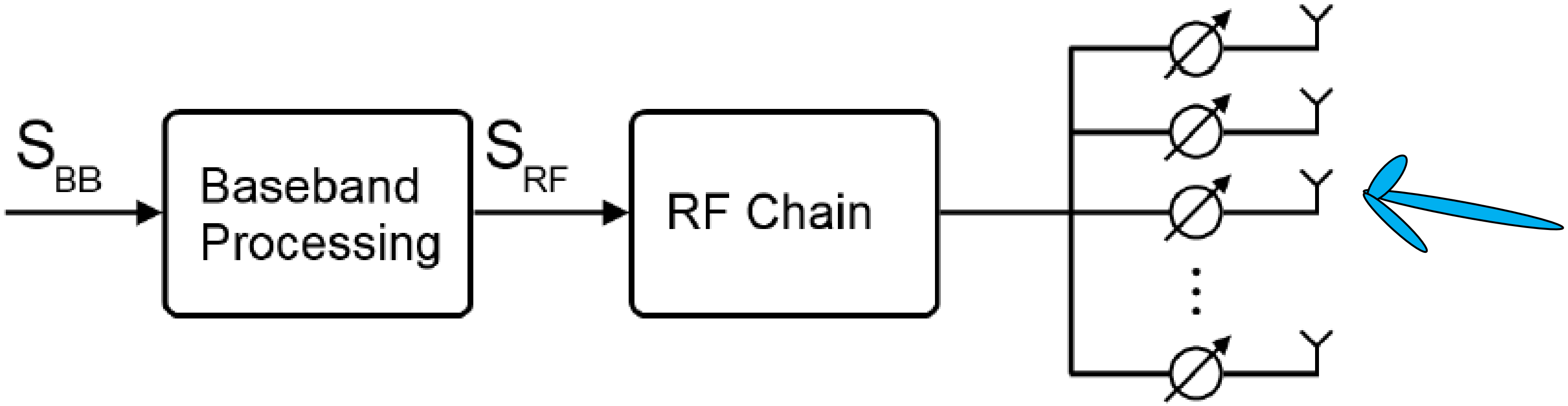
If the elements are too close, then there will be additional cross-talk

$$\Delta\varphi = \frac{2\pi}{\lambda} d \sin\Theta$$

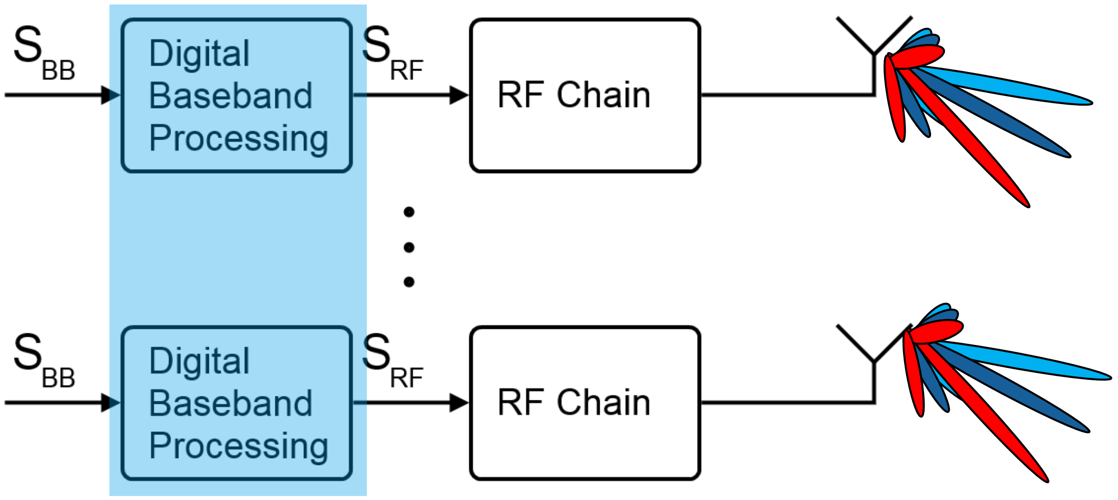




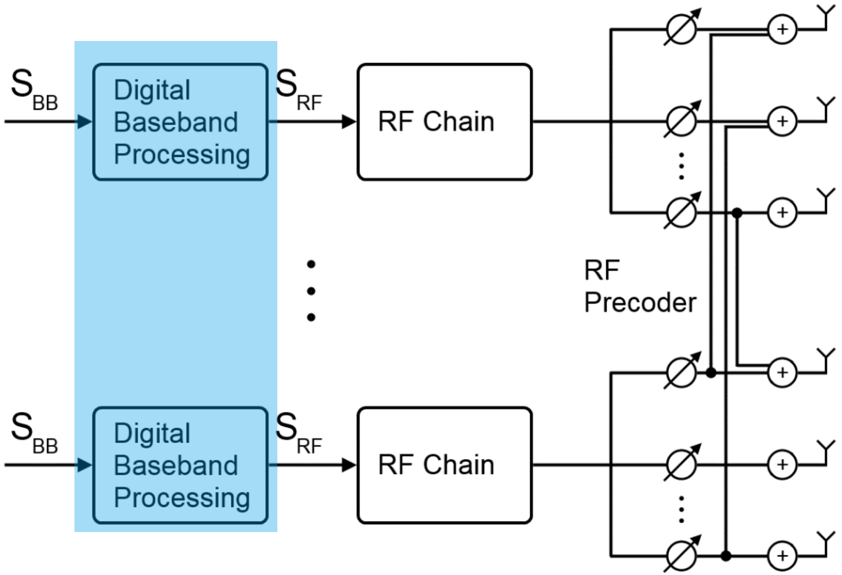
Analog beamforming concept



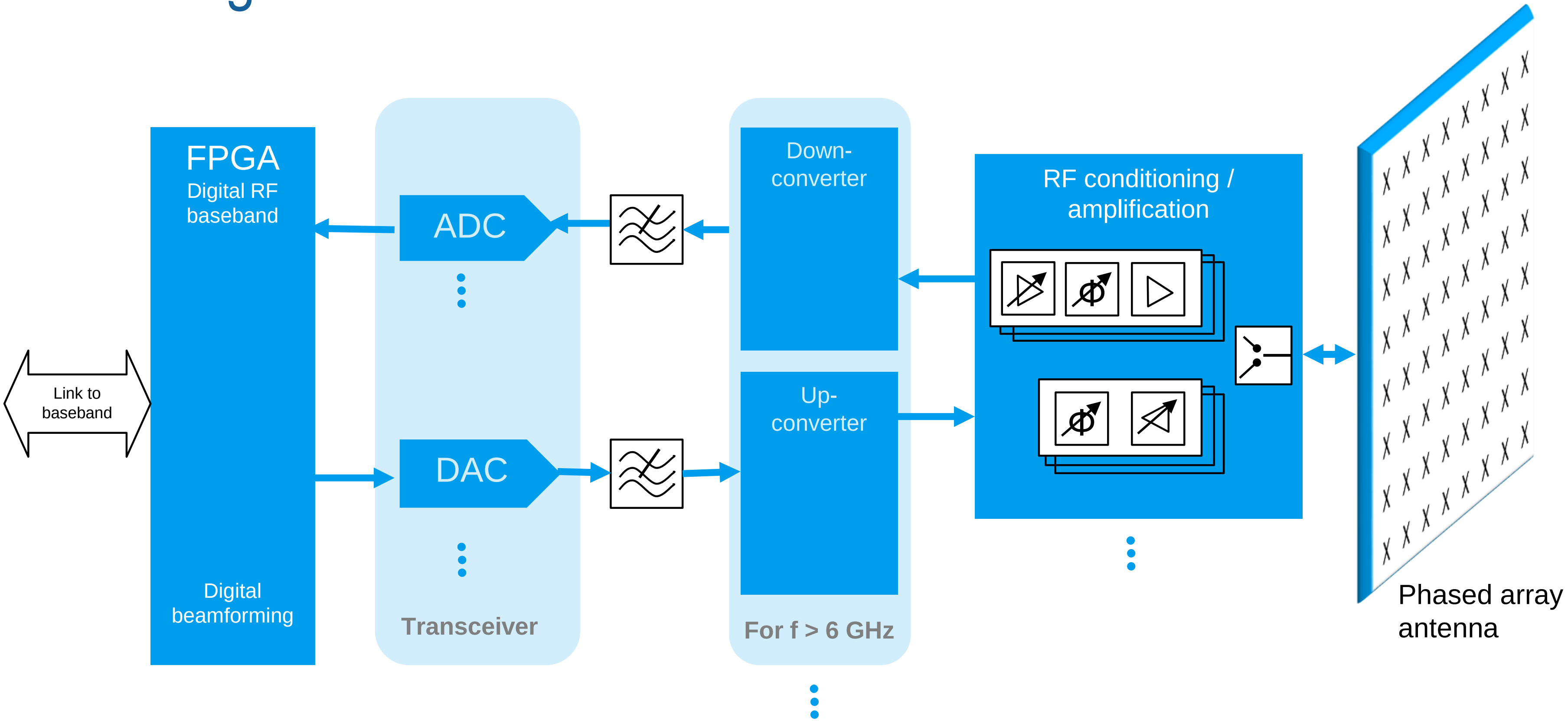
Digital beamforming concept



Hybrid beamforming concept



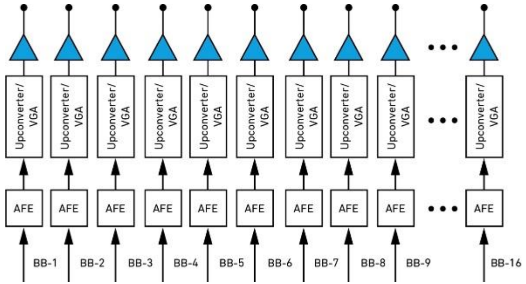
Block diagram of the RF section



Beamforming implementation

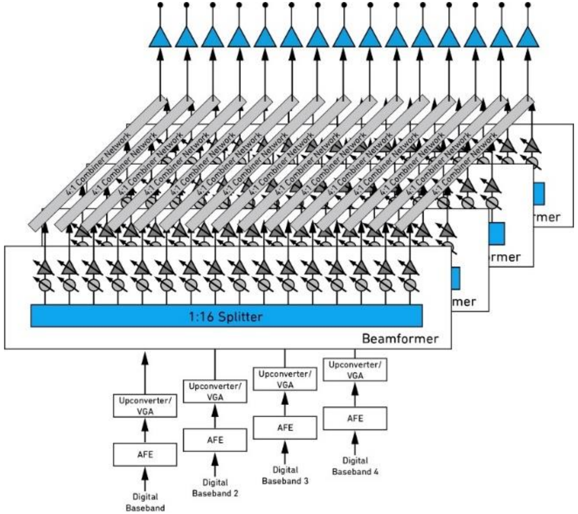
Digital

- Less elements, typ. up to 128
- Straight forward
- Requires more power per element



Hybrid

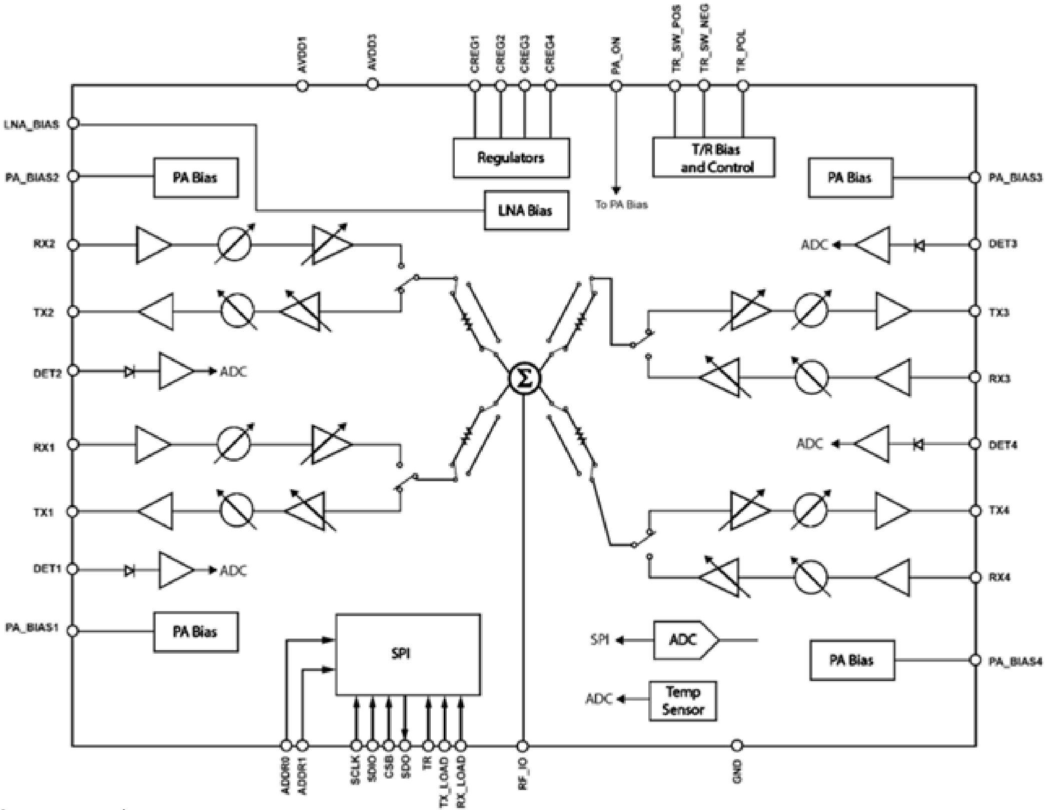
- More elements, up to 1000 and more
- Complex controls
- Less power per element



Example of a beamformer IC

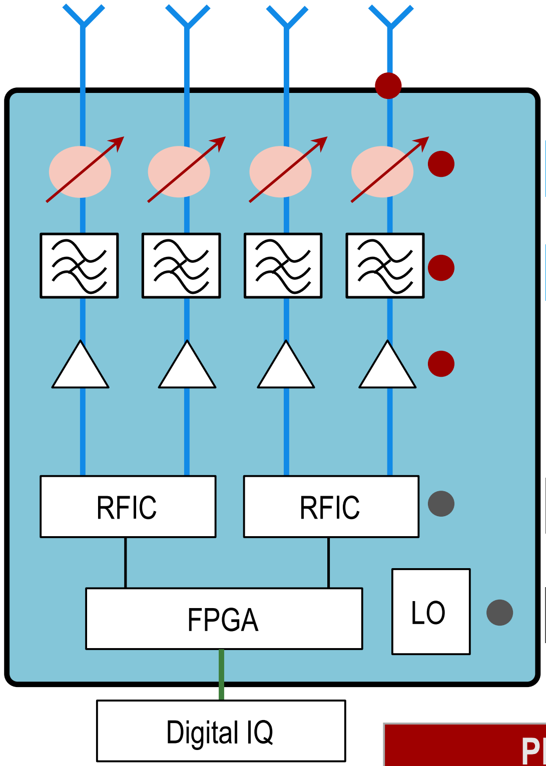
- Beamformer IC
- Example: ADI ADAR1000
- Addressing multiple antenna elements
- Can be cascaded

- Integration of
  - Phase shifter and level control
  - PA / driver
  - LNA
  - Switches



Source: www.analog.com

Active Antenna Arrays: The Calibration Problem



RF Feeding Network

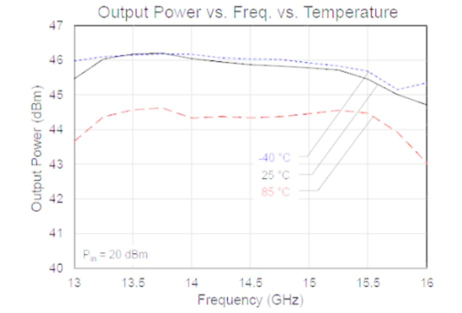
Phase Shifter Tolerances

Group Delay Variations

Dynamic Thermal Effects in PAs

Timing Errors in ADCs

Frequency Drift Between Modules



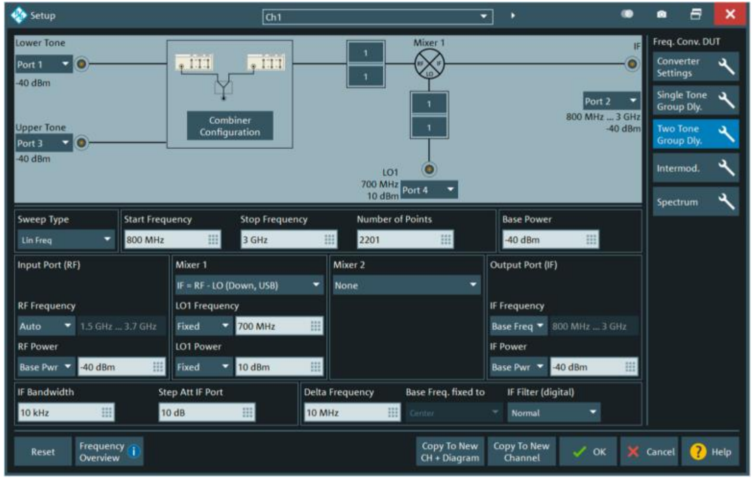
General
Manufacturing Tolerances of Components & Thermal Effects

Phase/Magnitude/Frequency Tolerances (Static & Dynamic)

Mixer test solution: ZNA

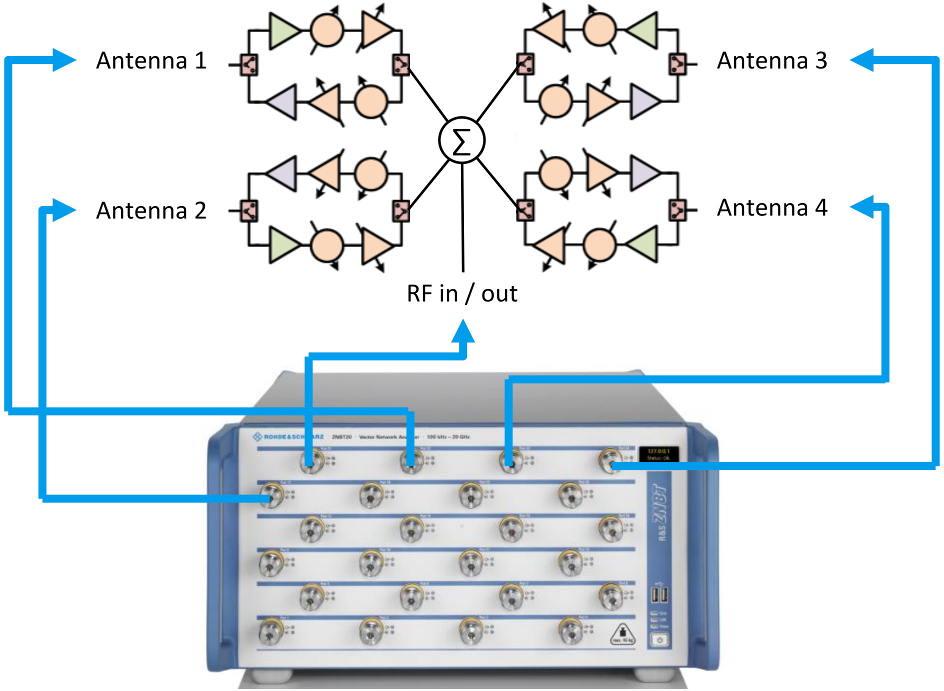
- **Relative phase measurements on mixers** thanks to phase-coherent and phase-repeatable sources without having to use a reference mixer

- 4 internal sources and 2 LOs for receiver frequencies offer maximum flexibility
- Parallel measurement on RF and IF gives 2x speed improvement for conversion loss measurement
- Swept LO measurements
- Intermodulation on mixer with frequency and level sweeps
- Group delay plus AM/AM and AM/PM conversion



Multiport solutions

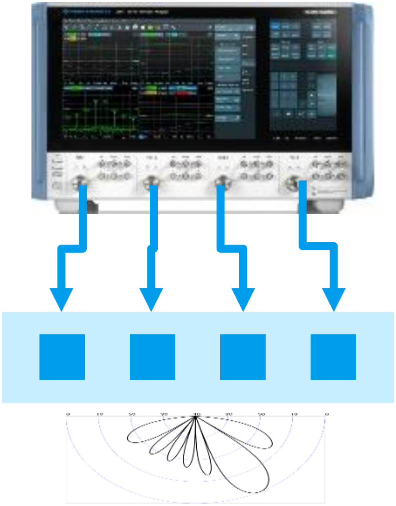
Using true multiport Vector Network Analyzers to characterize e.g. beamformer IC



Beamforming measurements

TX beamsteering

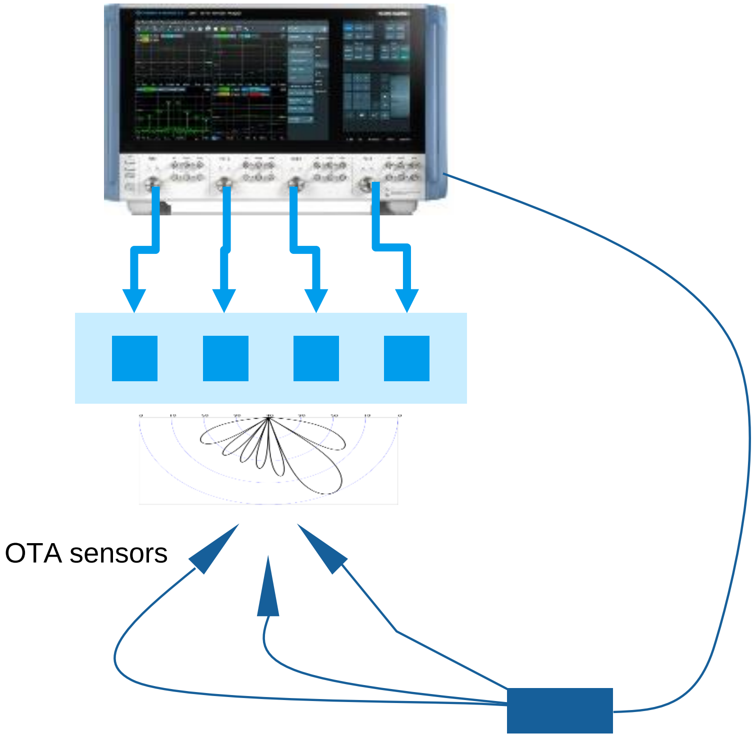
- VNA R&S ZNA offers 4 phase repeatable and adjustable sources



- SMW and SGS/SGU offers locking of LO supporting modulated signals with fixed phase relationship between channels

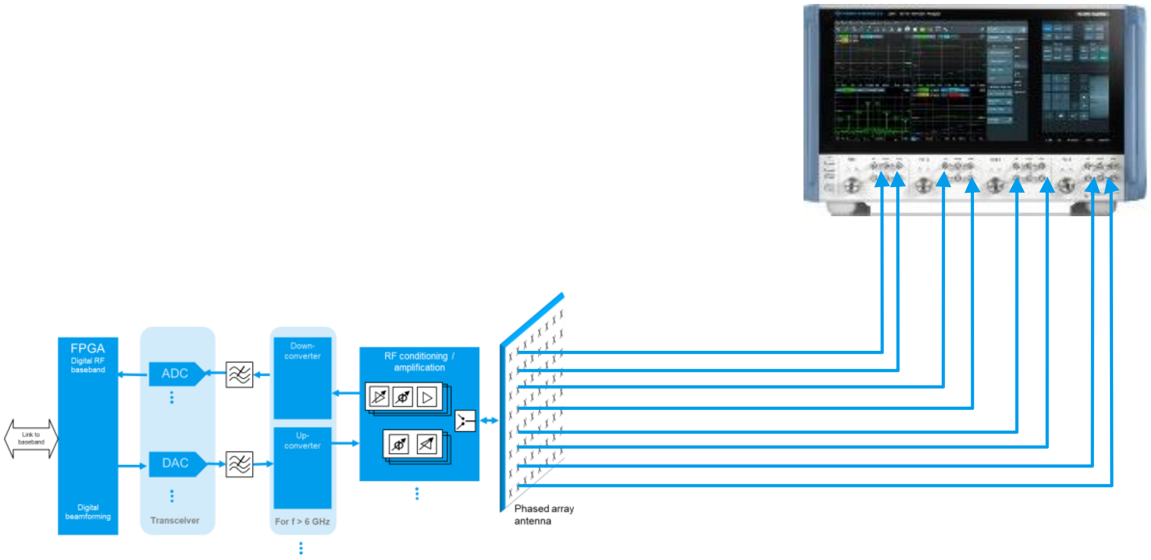
Beamforming calibration
TX beamsteering

- VNA R&S ZNA offers 4 phase repeatable and adjustable sources
- Combine with 3 OTA sensors
- Measure at 0°, +45°, -45°
- Done



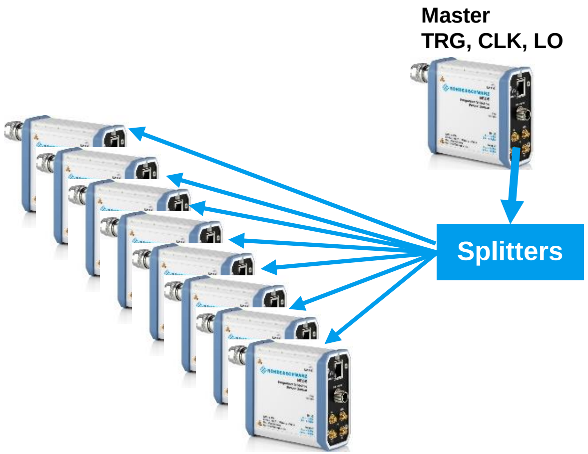
Beamforming measurements
RX testing

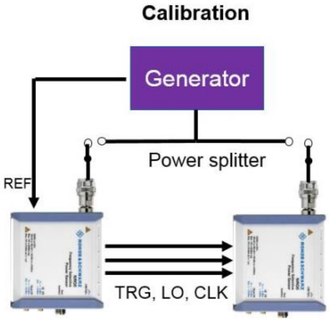
- ZNA offers 8 true receivers for parallel measurements for gain, phase etc – all CW parameters

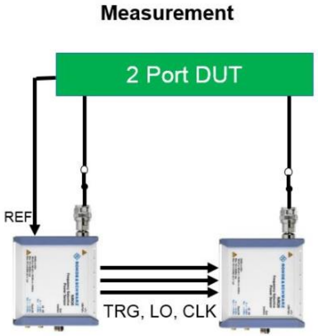


Beamforming measurements
RX testing

- Power, EVM, Phase between ports up to 6 GHz and 100 MHz of signal bandwidth
- Up to 8 ports tested
  - Star config works great. An additional (master) NRQ6 is recommended to provide LO, CLK and trigger for all slave instruments





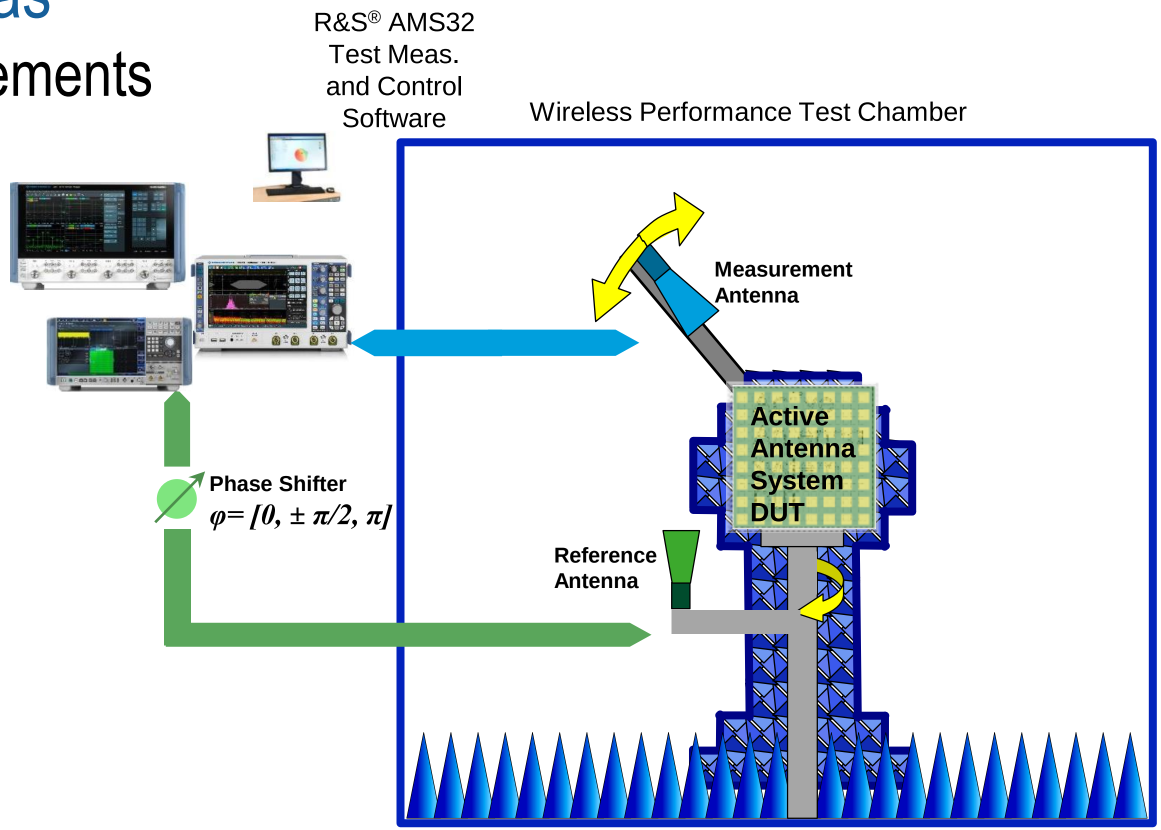


Testing of active antennas

OTA beamforming measurements

- Antenna gain
- Array antenna gain
  10 LOG N + single antenna gain

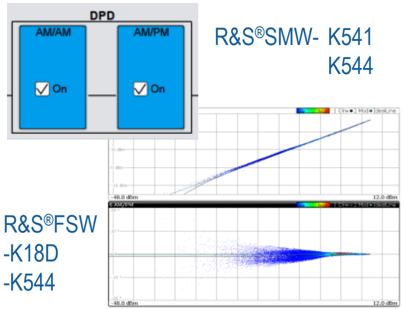
- EIRP
  Effective Isotropic Radiated Power
  = Pt * Gt
- Array EIRP = Pe + Ge + 20 LOG N



R&S test solutions for beamforming tests

Component Characterization

PA characterization and calibration



R&S®SMW- K541
K544

R&S®FSW
-K18D
-K544

Network Analyzer

R&S®ZNA

R&S®ZVA

Direct measurements up to 110 GHz

RF development

R&S®SMW200A–K144

R&S®SMW200A

UP

< 40 GHz

> 40 GHz

DUT

R&S®FSW85

R&S®FSW
-K144/K145

- 40 GHz signal generation
- 90 GHz signal analysis
- 2 GHz bandwidth support
  (FSW: 5GHz with RTO2064 and B5000)

Specific 5G NR Device Testing

Testing of 5G NR devices in non-signaling mode

R&S®CMW100
(Sub6)

R&S®CMP200
(mmW)

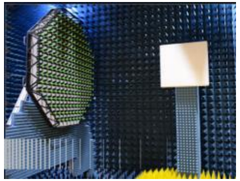
Testing of 5G NR devices in signaling mode

R&S®CMX500

R&S®CMWFlexx
supporting LTE for NSA operation

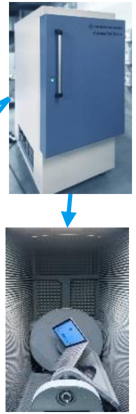
OTA solutions

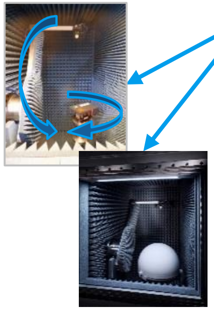
R&S®PWC200



R&S®NRPM

R&S®ATS1xxx





R&S®ATS800B

R&S®TS7124


"If you want to go fast, go alone.
If you want to go far, go together!"
African proverb